

# Characterisation of Sandstones: Mineralogy and Physical Properties

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**Abstract**— Sandstones from QwaQwa in South Africa were characterised for their mineralogical and physical properties. Six samples (whitish, greenish, blackish, reddish, yellowish and greyish) were collected and studied. The X-ray Diffraction (XRD) revealed that the samples were quartz based. Scanning Electron Microscopy coupled with energy dispersive X-ray spectroscopy (SEM/EDS) revealed the differences in the morphology and Silicon element was found present in all the samples. The X-Ray Fluorescence (XRF) exhibited that the samples contained 43.14% of Silicon (whitish). The grain sizes of the samples ranged from coarse, medium to fine grains. The Greyish sample had the highest compressive strength value of 56.74 MPa. Dielectric properties measurements were also conducted on the samples; and the results were temperature dependant. The water absorption by total immersion revealed that the blackish sand stones had the highest percentage of 6.62%.

**Keywords:** *dielectric properties, compressive strength Phase identification, water absorption.*

## I. INTRODUCTION

The characterisation and identification of minerals is fundamental in the development and operation of mining and minerals processing systems [1]. Worldwide, sandstones have been used as construction material for centuries and are still being used for this purpose [2]. Although, sandstones show similar appearances and properties; a geological background may cause differences in colour, mineral composition, granulometric properties, pressure strength and / or weathering behaviour [2]. On the other hand, mineralogical properties of sandstones could predict their mechanical properties such as the uniaxial compressive strength. The inherent parameters of sandstones can be characterised by their petrographical properties [3]. There is a large deposit of sandstones in QwaQwa in the Free State province of South Africa as shown in Fig 1. The presence of this large deposit of sandstones in the QwaQwa region was the motivation to initiate this study on the characterisation of sandstones. On the other, the knowledge on the physical such as compressive strength of QwaQwa sandstones will help the booming construction industry in South Africa by providing the characteristics of sandstones

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for construction and decorations purposes.

## II. GEOLOGY OF SOUTH AFRICA

The Free State lies in the heart of the Karoo Sequence of rocks, containing mudstones, shales, sandstones and the Drakensburg Basalt forming the youngest capping rocks [4]. The province is high-lying, with almost all the land being 1,000 meters above the sea level. Some of the sandstones are resistant to weathering yet easy to work. The geological map of South Africa indicating the QwaQwa region is displayed in Fig 1.

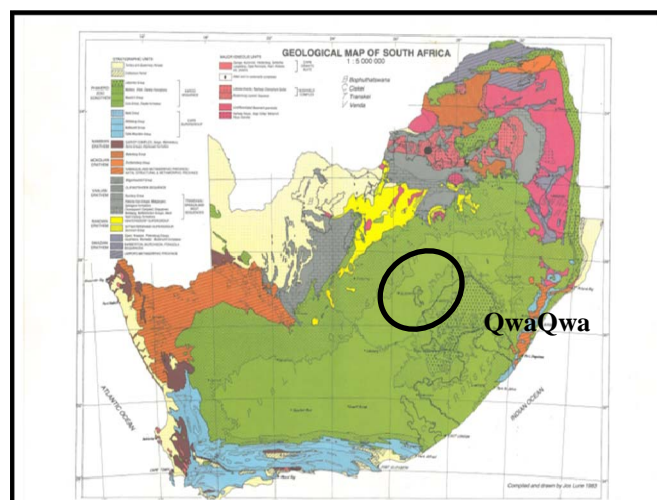


Fig.1. Geological map of South Africa showing the presence of sandstones in QwaQwa area of Free State [4]

Sandstones have been used as construction material worldwide and are still used for this purpose [5]. On the other hand, mineralogical properties of sandstones could predict their mechanical properties such as the uniaxial compressive strength. According to Zorlu et al., [3] the uniaxial compressive strength of sandstones is controlled by several inherent and environmental parameters. The inherent parameters can be characterized by the petrographical properties. The mineral composition, the void space, the degree of grain interlocking, the packing density and the grain size is known to be affected by the petrographic characteristics [3]. However, contradictory results have been reported relating the influence of mineral content on the geomechanical properties of sandstones [6]. It has been reported that rocks containing quartz as binding materials

are the strongest materials followed by calcite, and ferrous minerals; but rocks clayey binding materials are the weakest ones [7][3]. Furthermore, the shape of the grains is another petrographical property. The shape of the grains is usually expressed in terms of the roundness or sphericity, roundness being distinct from sphericity in that, it is concerned with the curvature of the corners. In fact, sphericity represents a quantitative means of expressing the departure of a grain from equidimensionality [6][3]. Shakoor and Bonelli (cited by [3]) found that there is a fairly strong relationship between the uniaxial compressive strength and the percent of angular grains [3]. On the other hand, Ulusay and co-workers (cited by [3]) reported that there is a strong correlation between the uniaxial compressive strength and the percent of rounded grains [3]. However, Fahy and Guccione cited by [3] obtained no meaningful correlation between the uniaxial compressive strength and the roundness while they found an extremely strong relationship between the uniaxial compressive strength and the sphericity of the grains. A study done by Zorlu et al., [8] did not obtain meaningful correlation between the uniaxial compressive strength and the grain shape parameters.

Within the framework of quantifying the natural stones in the QwaQwa area (South Africa) in term of quality, this paper is focusing on conducting mineralogical and physical characterisation of selected sandstones from QwaQwa rural area in South Africa.

### III. CHARACTERISATION TECHNIQUES

#### A. Mineralogy

The mineralogical studies of the sandstones were conducted using XRD, XRF and SEM combined with EDS. Moreover, the grain sizes measurements were conducted by using Olympus BX51M optical microscope on the mounted samples. On the other hand, the sandstones samples were crushed and milled using a jaw crusher and a milling machine, respectively. The powder obtained was then used for XRD and XRF analysis. The elemental composition of the sandstones was analysed using The Philips Magix Pro X-ray Fluorescence spectroscopy. An X-ray Powder Diffractometer (XRD) Phillips X'pert Model 0993 to determine their mineralogical phases. A SEM JEOL JSM-840 combined with EDS instrument was used to analyse the surface morphology and qualitative analysis of the samples respectively.

#### B. PHYSICAL PROPERTIES

The uniaxial compressive strength was used to measure the capacity of the six types of sandstones to withstand a load. The uniaxial compressive strength result helped to investigate and correlate the use of the six types of sandstones as construction material along with their water absorption and mineralogy. The six sandstones samples were tested in confined uniaxial compression in room-dry condition. The six sandstones samples were cut into cubical shape with an approximately size of  $3 \times 3 \times 5 \text{ cm}^3$ . The

sandstones samples were then placed in the testing machine and loaded in compression at the Council for Scientific and Industrial Research (CSIR) laboratory (South Africa). An Amsler universal machine was used to determine the uniaxial compressive strength. On the hand, the water absorption analysis was performed using a total immersion method. The sandstones samples were cut in a cubical shape of approximately 70 grams. The samples were washed with distilled water in order to eliminate powdered material from their surfaces. Thereafter, the samples were dried in the oven at  $60^\circ\text{C}$  for 24 hours. The samples were then placed in a desiccator with dry silica gel to cool. They were removed from the desiccator, measured (weight), put in a container filled up with water until the samples were totally immersed. After 24 and 48 hours, the samples were measured (weight) and the water absorption percentage was calculated. Additionally, the dielectric constant and loss factor of samples placed in a microwave cavity are related to the shift in the resonant frequency and change in the Q-factor or the bandwidth of the resonance. Standard closed-form perturbation models exist for the resonant frequency changes due to a cylindrical dielectric sample in a cylindrical microwave cavity. The cavity used for these measurements resonates at 915 MHz, a frequency allocated for microwave heating purposes. Each sample was placed in a 6 mm ID quartz tube and the microwave properties measured in the dielectric measurement fixture. A conventional high temperature furnace was used to heat the sample in the quartz tube to the required temperature ( $1000^\circ\text{C}$ ). It was then rapidly lowered into the microwave test fixture for the measurement of the dielectric properties. This was repeated for each measurement temperature. A ramp and soak heating profile was used, with the temperature increased to the next value over a period of 30 minutes, with a 30 minutes soak at that temperature before the measurement was taken. A slow nitrogen purge was bled through the quartz tube to displace any oxygen present and prevent oxidation at high temperature. A vector network analyzer (model: Hewlett Packard 8753B) was used to measure the dielectric properties of the sandstones specimens. The dielectric measurements of the samples were carried out at DELPHIUS CIT Laboratory (South Africa).

### IV. RESULTS AND DISCUSSION

#### A. Mineralogy and surface morphology

A representative fraction of the overall samples were analyzed to establish the starting point for the experiment. The diffractograms (Fig 2 and 3) show the XRD patterns of the reddish and blackish sandstone samples from QwaQwa rural area in South Africa.

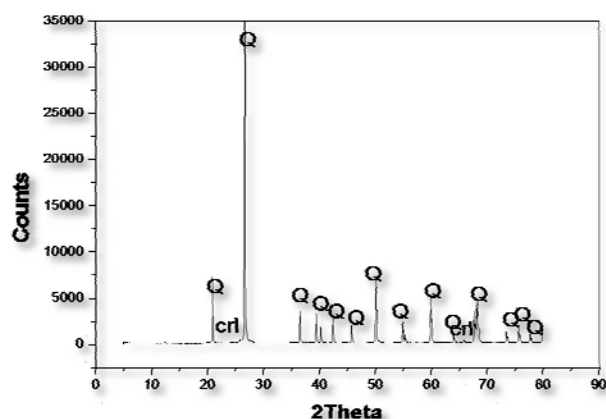


Fig.2. XRD graph of Reddish sandstone showing the minerals identified (Q= Quartz, crl= Crysolbilit).

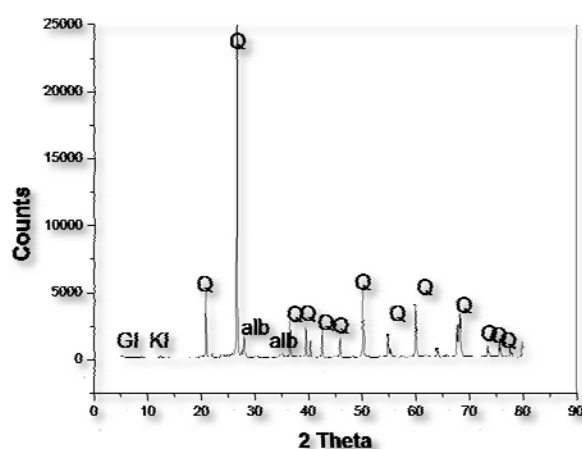


Fig.3. XRD graph of blackish sandstone showing the minerals identified (Q= Quartz, alb = Albite, Gl = Glauconite, Kl= Kaolinite)

The XRD analysis revealed that the Quartz ( $\text{SiO}_2$ ) was the major mineral present in all the sandstones followed by feldspar minerals such as Illite ( $(\text{K}, \text{H}_3\text{O}) (\text{Al}, \text{Mg}, \text{Fe})_2 (\text{Si}, \text{Al})_4 \text{O}_{10} [(\text{OH})_2, (\text{H}_2\text{O})]$ ), Albite ( $\text{Na Al Si}_3 \text{O}_8$ ). Other identified minerals include Glauconite ( $(\text{K}, \text{Na})(\text{Fe}^{3+}, \text{Al}, \text{Mg})_2 (\text{Si}, \text{Al})_4 \text{O}_{10} (\text{OH})_2$ ) Kaolonite ( $\text{Al}_2 \text{Si}_2 \text{O}_5 (\text{OH})_4$ ), Crysolbilit ( $\text{SiO}_2$ ) and Orthoclase ( $\text{KAlSi}_3 \text{O}_8$ ) were minor in the composition.

The XRF results are shown in Table 1. The chemical elements for the six types of QwaQwa' sandstones identified were: Aluminium (Al), Calcium (Ca), Iron (Fe), Potassium (K), Magnesium (Mg), Manganese (Mn), Sodium (Na), Phosphorus (P), Silicon (Si) and Titanium (Ti).

Table.1. Chemical composition of six of sandstones samples using XRF

Elem ents	Concentration (%)					
	Whitish	Yellowish	Blackish	Reddish	Greyish	Greenish
Al	2.00	4.01	4.62	1.92	4.66	4.81
Ca	-	0.09	0.23	0.03	0.10	0.40
Fe	0.42	0.83	2.04	1.39	1.44	1.32
K	1.01	1.87	0.85	0.59	1.58	1.71
Mg	0.06	0.19	0.38	0.05	0.32	0.28
Mn	-	-	0.30	-	-	-
Na	0.06	1.52	0.71	0.09	0.66	1.62
P	-	-	0.03	-	0.03	0.02
Si	43.14	39.10	38.81	42.76	39.48	38.18
Ti	0.06	0.14	0.26	0.10	0.19	0.16

The results in Table 1 revealed a significant presence of Silica in all the sandstones types implying that the QwaQwa' sandstones are silica based. The XRF results correlate to a very large extent with the XRD findings. This is in particular with regards to the dominance of the silicon species followed by Al and Fe. Mn was found in trace level only in the blackish sample whereas P which is also at trace level is evident in three samples: blackish, greyish and greenish as presented in Table 1. In addition, Ti although at negligible percentage is available in the six samples. The presence of these elements in the sandstones could be attributed to the origin of the mineral bearing.

Furthermore, Fig 4 and 5 show the SEM/EDS micrographs revealing the surface morphology and the chemical composition of the spotted grains for the blackish and greenish sandstones. The correlation between the XRD, XRF results and SEM/EDS is once again evident based on the elemental chemical composition of the spotted grains which reveals Si followed by Al and Fe as the main components. This is in accordance with the chemical composition of phases found using the XRD analysis (Fig 2 and 3) and the chemical composition using XRF displayed in Table 1. Furthermore, the results from the optical microscopy analyses conducted revealed that the samples had a wide range of grain sizes which range from coarse, medium to fine grains. The whitish sandstone had coarse grains while the reddish and blackish had medium-coarse grains. On the other hand, the greyish, yellowish and the greenish have medium-fine, fine and fine grains respectively. Fig 6 and 7 show the grain sizes of the whitish and yellowish sandstone respectively.



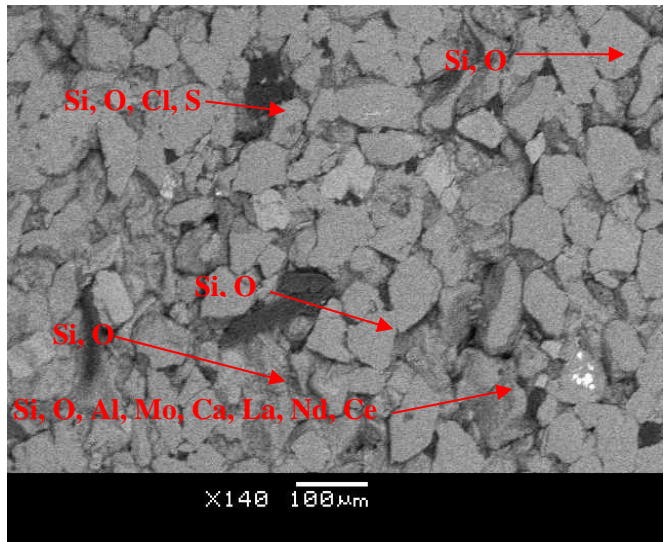
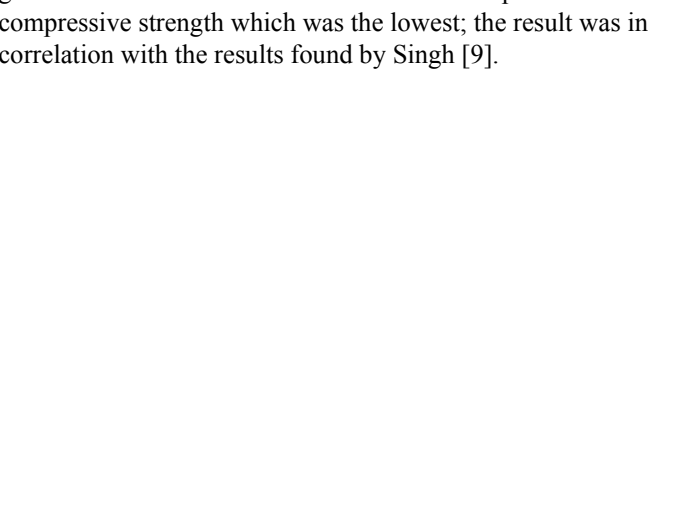


Fig.5. SEM combined with EDS micrograph of the greenish sandstone showing the surface morphology and the chemical composition of the spotted grains respectively



The uniaxial compressive strength of intact rock is among the main parameters used in almost all engineering projects. The uniaxial compressive strength test requires high quality core samples of regular geometry [3]. Fig 8 and 9 show the graphs of the compressive stress versus compressive extension of the greyish and yellowish sandstones under a load. The loads were recorded and the unconfined compressive strength of the sandstone was determined. The uniaxial compressive strength of the six QwaQwa' sandstones samples recorded were 9.4 MPa, 22.8 MPa, 26.3 MPa, 16 MPa, 8.3 MPa and 56.7 MPa for yellowish, reddish, greenish, blackish, whitish and greyish, respectively. The whitish sandstone has the lowest compressive strength (8.3 MPa) whereas the greyish shows the highest value (56.7 MPa). Furthermore, Singh [9] and [3] and Zorlu et al., [3] stated that the uniaxial compressive strength also vary with the grain size range. Therefore, it was observed that a good correlation exists between the grain size of the whitish sandstone sample and the compressive strength which was the lowest; the result was in correlation with the results found by Singh [9].

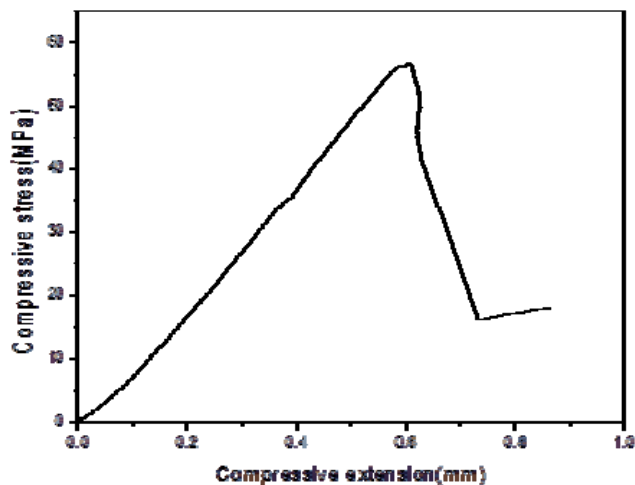


Fig.8. Compressive stress versus compressive extension of greyish sandstone. The uniaxial compressive stress was measured to be 56.7 MPa.

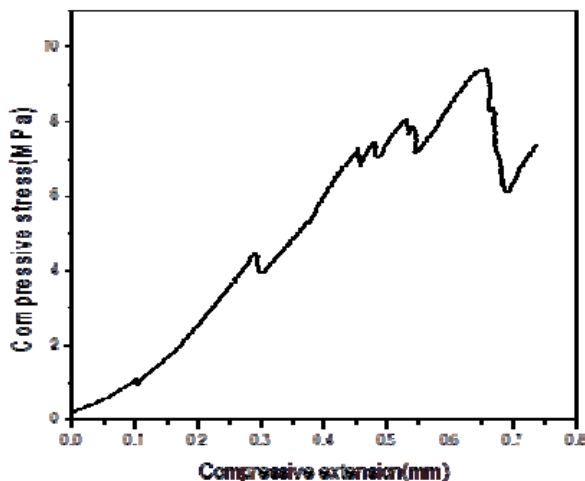


Fig.9. Compressive stress versus compressive extension of yellowish sandstone. The uniaxial compressive stress was measured to be 9.4 MPa.

The water absorption using dried sandstones was performed. The graphs of the water absorption by mass change and percentage are displayed in Figure 10 and 11. The percentage of water absorption ability of the samples was as followed in a descending order; blackish (6.6%), greenish (6.4%), whitish (6.0%), reddish (5.9%), yellowish (5.8%), and greyish (2.7%) as shown in Figure 11. Figure 10 shows the water absorption by mass change. The water absorption results suggest that the greyish samples absorbed less water than the other samples. A correlation between the water absorption and the grain sizes for some of the sandstones samples (yellowish, blackish, reddish, whitish, and greyish) was noticed. However, the blackish sample had medium fine grain size. On the other hand, the blackish sample showed the highest water absorption which could be assumingly due to its higher porosity.

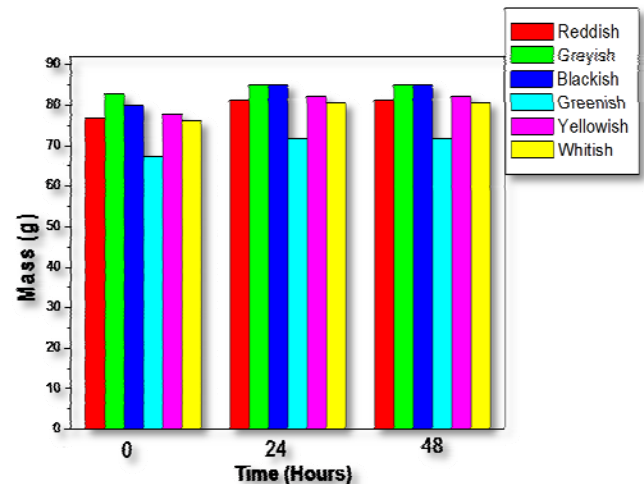


Fig.10. The water absorption mass change of dried sandstones, samples were dried overnight in an oven and immersed in water for 24 and 48 hours.

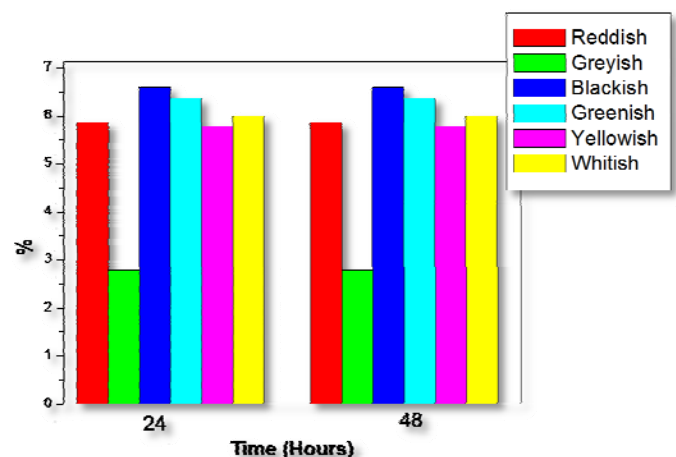


Fig.11. The water absorption percentage of dried sandstones, samples were dried overnight in an oven and immersed in water for 24 and 48 hours.

The knowledge of the dielectric properties or permittivity of granular or powdered materials is an important parameter in the application of the dielectric heating or sensing moisture content using radio frequency or microwave instruments [10]. Six sandstones samples were used for the microwave dielectric measurements. The microwave dielectric constant and the loss factor measured were found to be temperature dependant. This is shown by the results obtained which varied with the temperature. The dielectric constant and loss factor results ranged from 2.45-3.19, 2.39-3.51, 2.20-2.51, 1.80-2.51, 2.59-2.98, 2.56-2.87 for the greenish, reddish, yellowish, greyish, blackish and whitish sandstones respectively. On other hand, the dielectric loss factor ranged from 0.14-0.52, 0.01-1.01, 0.01-0.19, 0.01-0.18, 0.07-0.37 and 0.001-0.137 for greenish, reddish, yellowish, greyish, blackish and whitish respectively. The dielectric results exhibited in Fig 12 and 13 are for the greenish and blackish sandstones respectively. Moreover, the tangent delta ( $\tan \delta$ ) was calculated using the dielectric



constant and loss factor results in the following equation:

$$\tan \delta = \epsilon''/\epsilon' \dots \dots \dots (1)$$

where  $\epsilon'$  = dielectric constant  $\epsilon''$  = dielectric loss factor

It has been reported that the correlation between the dielectric properties or permittivity and water content of hygroscopic materials for sensing moisture content is important [10]. In our case, the dielectric properties measured were used to simulate the electric field and power absorption distribution using HFSS software for the design of a microwave heating cavity.

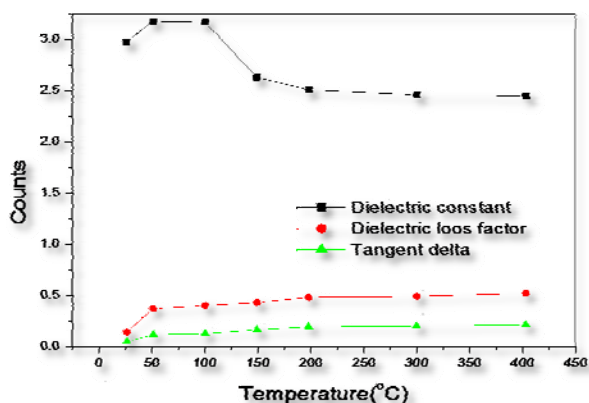


Fig.12. Dielectric constant, loss factor and calculated tangent delta of Greenish showing the temperature dependency

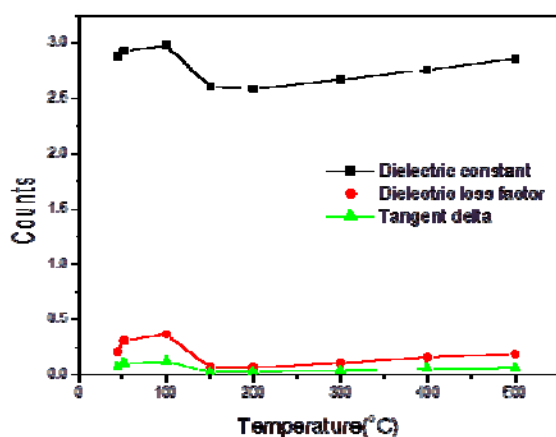


Fig.13. Dielectric constant, loss factor and calculated tangent delta of Blackish showing the temperature dependency

## V. CONCLUSION

The mineralogical and physical characterisation of QwaQwa sandstones (South Africa) was successfully achieved. The XRD diffractograms confirmed that the sandstones are quartz based minerals along with traces of Kaolinite, Illite and Albite. Optical microscopy analyses revealed that the QwaQwa sandstones had grain sizes

ranging from fine to coarse grains size. Both EDS and XRF results were in good correlation by exhibiting Silicon as the highest chemical element on the sandstones. On the other hand, the compressive strength and water absorption demonstrated a complexity in the ability for the samples to absorb water and to sustain a load. Thus, the results of the characterisation studies provided good mineralogical and physical properties of different types of sandstones. Furthermore, sample collections at different sites in the QwaQwa rural area are encouraged. The collections will assist to conduct more characterisation and confirm the findings in this study thus to create a database of identical physical and mineralogical properties results for the whole QwaQwa area which is desirable for use in the construction industry.

## ACKNOWLEDGMENT

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## Modifications

A modification was made on the "ACKNOWLEDGEMENT" section. The modifications were made on the 10 June 12, 2013.